TOTAL NEUTRON-NUCLEI CROSS-SECTIONS AT 10 GeV/c

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Total neutron cross-sections were determined for He, Li, Be, C, Al, Fe, Cu and Pb at an average neutron momentum of 10 GeV/*c*. The results agree very well with total proton-neuclei cross-sections at 20 GeV/*c*. The interaction radii inferred from the cross-sections are in remarkable agreement with the half-density radii as obtained from electron scattering.

The investigation of neutron scattering from nuclei at high energies can increase our knowledge on the nuclear structure. In contrast to proton-nuclei scattering Coulomb scattering does not interfere and no corrections are necessary in order to determine radii or other nuclear parameters. On the other hand a comparison between proton and neutron scattering could give information on the existence of a real scattering amplitude and perhaps also on differences of the proton and neutron distribution in nuclei.

Here measurements of total neutron-nuclei cross sections are reported for targets ranging from helium to lead. From these results interaction radii can be extracted by using a simple optical model.

The experiment was performed with a neutron beam at the CERN PS which had been used to study the neutron scattering from hydrogen and deuterium. This beam has been described previously [1]. The targets were placed 38.8 m from the neutron detector (position T 1 of fig. 1 in ref. 1). The proton energy was 19.3 GeV for all measurements which produced neutrons at an angle of 2.7° with an average momentum of 10 GeV/*c*. The total flux at the target was about 30 000 neutrons per burst of 5×10^{11} protons. Much effort was spent in obtaining a well defined geometry with good beam definition. Since the experiment was performed on a parasitic basis sufficient beam-time was available not only for obtaining good statistical accuracy but also for eliminating systematic errors.

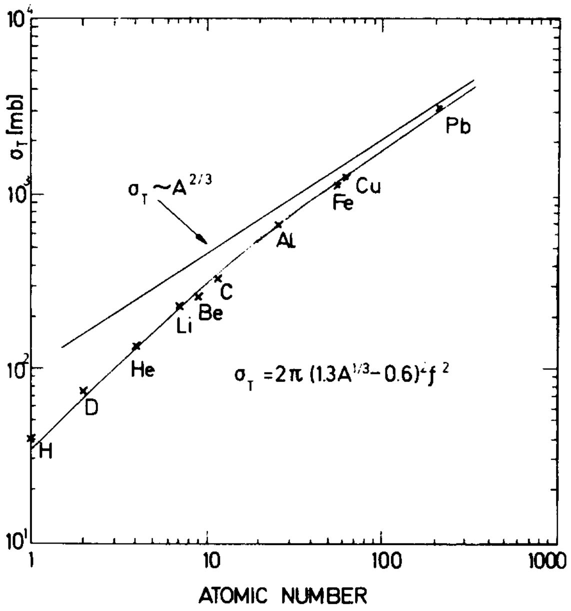

Fig. 1. The total cross-section for neutron-nuclei scattering at 10 GeV/*c* as a function of atomic mass *A*. The values for *H* and *D* are taken from a previous paper [1].

The main source of systematic errors is the small angle scattering. To keep it small the target-detector distance was made as large as possible. Furthermore measurements with five iron converters (2 cm thick) of different sizes

(4×8 cm^2, 6×10 cm^2, 9.5×13.5 cm^2, $13 \times \times 17$ cm^2 and 16×20 cm^2, with beam size $4.2 \times \times 8.5$ cm^2 at converter) were performed and the cross section was obtained from an extrapolation to converter size zero. In addition the beam profile with and without target was measured with a pencil-counter.

The cross-sections were derived from absorption curves except for He. For LiH, Be, C and Al four to six different target thicknesses were used which varied between 0.1 and 1.5 collision lengths. For Fe, Cu and Pb, absorption curves in steps of 0.78 g/cm^2 for Fe, 0.89 g/cm^2 for Cu and 1.1 g/cm^2 for Pb were taken. The statistical accuracy was better than 1% for each target thickness and each converter size. For He only a target full-empty measurement was done. A steel cylinder filled to a pressure of $147.5 \pm \pm 0.5$ atm was used as target container.

For Al and lighter elements the small angle scattering correction was negligible whereas it had to be taken into account for Fe, Cu and Pb. For the last three elements two additional effects were found. First absorption curves showed two distinctly different slopes in a logarithmic plot. The steeper slope was caused by the absorption of γ rays ($\sim$ 1%) and could be eliminated by adding 5 cm lead. Secondly it was observed that the ratio of counting rates with and without target increased with increasing converter size. This may be due to the scattering and probably production of secondary neutrons. By extrapolating to converter size zero the absorption curves gave a straight line. The total cross-sections of these elements were derived from the slopes.

The results are shown in table 1 together with other measurements. Our values for the neutron-nuclei cross-section at 10 GeV/c are systematically higher than those reported previously [2,3] at 27 GeV/c and 8.3 GeV/c respectively, but are in very good agreement with proton-nuclei data at 20 GeV/c [4]. This agreement indicates that the real part of the scattering amplitude is negligible since its interference with the Coulomb amplitude contributes to the proton but not to the neutron scattering.

The dependence of the total neutron-nuclei cross-section on the atomic number A is shown in fig. 1. From an optical model applied to a sphere with radius R and uniform opacity a one obtains σ_T - $2\pi\, aR^2$. With $R \sim A^{1/3}$. However, as can be seen from fig. 1 the experimental cross-sections show a steeper slope.

The optical model can be refined by allowing the opacity $a(b)$ to change with the impact parameter b in which case one has $\sigma_T = 4\pi\int_0^\infty ab\,db$. If for $a(b)$ a Fermi distribution characterized by an interaction radius R and a skin thickness parameter t is assumed, one finds $\sigma_T \sim 2\pi(R^2 + t^2)$. Since t should not change appreciably with A the slope of σ_T becomes even flatter than for $t = 0$. Hence a more sophisticated model is required to explain the measured cross-sections.

In the lack of a better model an empirical fit is tried by putting $R_{eff} \sim A^{1/3}$ + const. Surprisingly the experimental data can be represented down to the lightest nuclei by $\sigma_T = 2\pi(1.3A^{1/3} - - 0.6)^2$ fm^2 (see fig. 1). The parameters determining the effective interaction radius are in remarkable agreement with those of the half-density radius $r_{0.5} = 1.18\, A^{1/3} - 0.48$ as determined from electron scattering [5]. This agreement might be fortuitous since the size of the nucleon and the range of nuclear forces besides other ef-

Table 1.
Total cross-sections for nuclei

Nucleus	A	σ_T[mb] 10 GeV/c neutrons [this experiment]	σ_T[mb] 27 GeV/c neutrons [2]	σ_T[mb] 8.3 GeV/c neutrons [4]	σ_T[mb] 20 GeV/c protons [3]
He	4	141 ± 6	-	-	-
Li	7	237 ± 7	-	-	250 ± 5
Be	9	271 ± 6	250 ± 6	-	278 ± 4
C	12	340 ± 3	300 ± 7	345 ± 15	335 ± 5
Al	26.9	683 ± 3	573 ± 17	600 ± 23	687 ± 10
Fe	55.8	1204 ± 12	1023 ± 25	-	-
Cu	63.5	1364 ± 14	1090 ± 30	1217 ± 48	1360 ± 20
Pb	207.2	3146 ± 50	2630 ± 120	2556 ± 100	3290 ± 100

fects, should lead to an interaction radius different from the electromagnetic radius.

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